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Analytical method of determining the movement resistance of a tip for forming rectangular technological hole in the lower structure tracks

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Abstract. The aim of this work is to theoretically determine the total resistance to soil pricking with a wedge-shaped tip to create a rectangular cavity and to determine the influence of the size of the working equipment and soil environment in the repair of earthenware or areas where trench technology can-not be used. To determine the forces of the recess of the replaceable pilot, the law of change of soil pressure on the working surfaces of the working equipment was first determined, which is based on the idea of the change of the soil elastic state at its compaction was determined, which is determined by the compression module of deformation of the soil. The processes occurring during the formation of wells and new approaches to the improvement of calculations have been described. On the basis of the pro-posed model of the piercing process, the laws of change of the normal pressure of soil resistance on the surface of the wedge working equipment are established. Based on its value, the results of theoretical studies have received a rational form and parameters of the tip of the work equipment.

1. Introduction

Static perforation of the soil for trenchless laying of underground distribution communications, when repairing the ground or adjacent territories where it is impossible to use trench technology, is the most effective method of forming a horizontal well. In this paper, a method of determining the soil resistance at its perforation is proposed with a tip to form a well of a rectangular cavity.

Installation of underground communications under railway objects and in compressed urban conditions requires simultaneous laying of several linear-extended objects (LPOs), or their protective flares, through one common cavity. Substantiation of rational design of soil-boring working equipment for simultaneous laying of two or more communications and establishment of its parameters is an urgent task.

The purpose of the work is to determine the soil resistance during its perforation with a wedge-shaped tip for forming a rectangular cavity.



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2. Analysis of literary data and raising of problem

The deterioration of underground railway networks and facilities serviced by rail requires the gradual replacement, modernization or construction of new utility networks, which imposes certain restrictions on builders [1, 2] and requires the simultaneous laying of several lines of the same type. Objects (LPOs) in protective cases through one common pore. For objects not related to train movement but only servicing the railway, restrictions are now imposed on the possibility of an open method of performing works for the construction of underground communications. Therefore, trenchless methods of laying underground communications are becoming widely used [3, 4]. The main disadvantage of these technologies is their cost, which comes from the high cost of drilling equipment and the cost of performing the work. Of the variety of methods available in the market for obtaining technological cavities in soil, the simplest and cheapest is the static puncture [5, 6].

The general regularities of soil puncture processes and the formation of horizontally directed boreholes are described in [6, 7, 8]. The influence of the process of piercing the soil on the ground [9, 10], rolling stock and its elements, as well as neighboring communications are considered in [11, 12,]. The results of studies to determine the effort of piercing a conical tip are described in [13, 14, 18] the influence of the design parameters of wedge-shaped working bodies on the process of soil destruction laid out in [15, 16]. Changes in soil quality in the surrounding well space during static soil puncture and their influence on the processes of formation of the well and its expansion have been considered in [10, 17]. Requirements for simultaneous laying of two or more communications or their protective cases through a common cavity of a cylindrical shape, as well as the possibility of controlling the trajectory of a static puncture are set out in regulatory documents [1, 2, 10]. Studies on the definition of rational parameters of the tip of the soil piercing working body of the conical shape are considered qualitatively in [8, 13], and options for controlling the trajectory of the cavity [19].

For the first time, this cross-sectional shape of the hole was considered and an analytical dependence of the resistance of movement of the working body on the shape of the working body and the number of linearly extended objects being laid simultaneously were created. The obtained dependences allow to state that in this form of aperture, depending on the number of communications that are laid simultaneously, it is possible to reduce the effort up to 2 times, as well as to reduce the area of structural changes in the soil around the received cavity in comparison with the traditional conical tip.

Purpose. It is known from [9] that puncture of soil by a conical tip can be effective within the diameter of the well, which is obtained from the condition of optimal resistance. Thus, it was found that the maximum reduction in puncture resistance occurs: for a solid loam at diameters m , for a semi-solid loam at diameters m , for a rigid plastic clay at diameters m . attention to the fact that their diameters are at least 100 mm. According to [2], the number of jointly laid protective cases in the form of steel or plastic pipes is from 3 to 8 pieces. However, the problem remains of the presence of cavities when laying several individual cases in one hole, which leads to soil subsidence, along the course of a puncture or collapses.

3. Influence of the wedge working equipment on the earthen cloth

We propose the construction of a soil perforation working equipment (Figure 1) for the simultaneous laying of two or more cases 3 for communications or drainage under embankments, consisting of a perforation wedge part 1 with half cones and a calibration part 2 in the shape of a rectangular cavity with a half-cylinder.

Determine the law of change in soil density in thickness d tip on the basis of equality of mass [13], which according to the scheme of action of normal soil pressure on the working equipment (Figure 1) has the form:

$$(n-1)d^2\rho_{nat} = (n-1)d(d-2x)\rho_x, \quad (1)$$

$$\rho_x = \frac{\rho_{nat}}{1 - \frac{2x}{d}}, \quad (2)$$

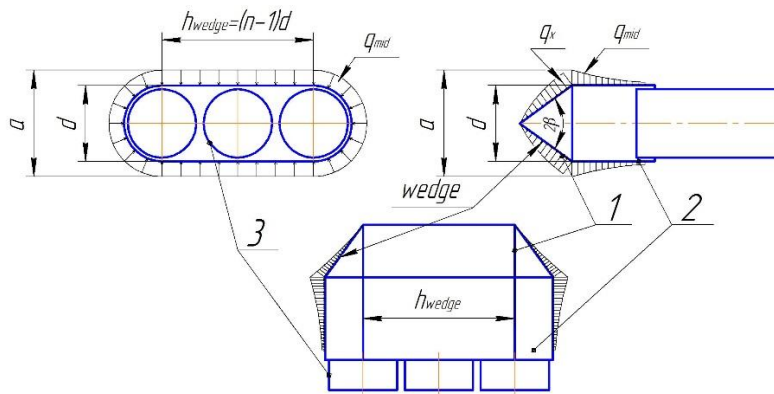


Figure 1. Cross-section replaceable pilot wedge-type and arrangement of loads on it: 1 – wedge-new piercing part with half cones; 2 – calibrating parts-on; 3 – Cases.

Change of normal soil pressure on the front surface of the tip [13] based on expressions (1) and (2) will be written in the form:

$$q_x = E_{soil} \frac{2x}{d}, \quad (3)$$

where $E_{soil} = \frac{1+\omega}{c_k} \frac{\rho_{hard}}{\rho_{nat}}$ – compression modulus of soil deformation; x – deformation of the soil by the front surface of the tip; d – the diameter of the linear-elongate element LEE; n – the number of LEE being laid simultaneously.

The resistance of the wedge tip consists of the resistance of the wedge width h_{wedge} and height d the resistances of the two extreme half cones equivalent to the resistance of one cone with a diameter d .

$$P_{equiv. force} = P_{wedge} + P_{cone}. \quad (4)$$

Determine the resistance of the wedge:

$$dP_{wedge} = q_x dF \sin \beta (1 + f \cdot \text{ctg} \beta), \quad (5)$$

where dF – elemental area of the front surface of the wedge ($dF = dh \cdot \frac{dx}{\sin \beta}$); 2β – angle of sharpening of the wedge; f – wedge friction coefficient.

Then substituting the value (3) in (5) we obtain:

$$dP_{wedge} = E_{soil} \frac{2x}{d} dh \frac{dx}{\sin \beta} \sin \beta (1 + f \text{ctg} \beta), \quad (6)$$

$$P_{wedge} = E_{soil} \frac{4h_{wedge}}{d} (1 + f \cdot \text{ctg} \beta) \int_0^{d/2} x dx = \frac{d \cdot h_{wedge}}{2} E_{soil} (1 + f \cdot \text{ctg} \beta), \quad (7)$$

$$P_{wedge} = \frac{(n-1)d^2}{2} E_{soil} (1 + f \text{ctg} \beta). \quad (8)$$

Obviously, the analytical dependence of the total resistance on the total puncture resistance (4) consists of the resistance of the conical and wedge (6), (7) and (8) parts of the tip.

According to the previous work [13, 14, 15] of the authors the theoretically determined resistance to the indentation of the conical tip into the soil is equal to:

$$P_{equiv. force wedge} = P_{wedge} + P_{equiv. force cone} \quad \text{then} \quad P_{equiv. force cone} = \frac{\pi}{8} D^2 E_{soil} (1 + f \text{ctg} \beta), \quad (9)$$

where $D = d$ – for wedge-shaped working body of rectangular shape.

4. Results

A mathematical model for calculating the total drag of the working fluid in the soil has been created. The total drag is equal (Figure 2):

$$P_{\text{equiv. force wedge}} = \frac{\pi + 4(n-1)}{8} d^2 E_{\text{soil}} (1 + \text{fctg} \beta). \quad (10)$$

To obtain a rational form and parameters of working equipment determine the ratio of the frontal perforation resistance of conical (9) and wedge (10) tips:

$$\frac{P_{\text{equiv. force cone}}}{P_{\text{equiv. force wedge}}} = \frac{\pi D^2}{[\pi + 4(n-1)] d^2}. \quad (11)$$

Determine the dependence of the size of the circle, which is described around several cases laid side by side. Consider several options for stretching pipes by number: 2, 3, and n pieces.

If $n = 2$, then $D = 2d$, then by the formula (11):

$$\frac{P_{\text{equiv. force cone}}}{P_{\text{equiv. force wedge}}} = \frac{\pi D^2}{[\pi + 4(2-1)] d^2} = \frac{\pi 4d^2}{[\pi + 4] d^2} = 1.76. \quad (11, a)$$

If $n = 3$, then $D = 2.155d$, then by the formula (11):

$$\frac{P_{\text{equiv. force cone}}}{P_{\text{equiv. force wedge}}} = \frac{\pi 4.644d^2}{[\pi + 8] d^2} = 1.31. \quad (11, b)$$

If $n = 4$, then $D = 2.41d$, then by the formula (11):

$$\frac{P_{\text{equiv. force cone}}}{P_{\text{equiv. force wedge}}} = \frac{\pi 5.808d^2}{[\pi + 12] d^2} = 1.20. \quad (11, c)$$

In general, for any number of cases the Figure 3:

Consider the triangles $\triangle AOB$, $\triangle COD$ and $\triangle KOD$.

Angle $\angle KOD = \frac{\pi}{n}$, from where $\sin \frac{\pi}{n} = \frac{KD}{OD}$, $OD = \frac{KD}{\sin(\pi/n)}$, $OB = OD + DB$.

$$D = OB = \frac{d}{2 \sin(\pi/n)} + \frac{d}{2} = \left(1 + \frac{1}{\sin \pi/n}\right) d. \quad (12)$$

Then by formulas (11) and (12) we obtain:

$$\frac{P_{\text{equiv. force cone}}}{P_{\text{equiv. force wedge}}} = \frac{\pi \left(1 + \frac{1}{\sin \pi/n}\right)^2 d^2}{[\pi + 4(n-1)] d^2} = \frac{\pi \left(1 + \frac{1}{\sin \pi/n}\right)^2}{\pi + 4(n-1)}. \quad (13)$$

By formulas (11), (12) and (13) we obtain at $n = 5$.

$$\frac{P_{\text{equiv. force cone}}}{P_{\text{equiv. force wedge}}} = \frac{\pi \left(1 + \frac{1}{\sin \pi/5}\right)^2}{\pi + 4(5-1)} = \frac{\pi \left(1 + \frac{1}{\sin 36^\circ}\right)^2}{\pi + 16} = 1.2. \quad (13, a)$$

By formulas (11), (12) and (13) we obtain at $n = 10$.

$$\frac{P_{\text{equiv. force cone}}}{P_{\text{equiv. force wedge}}} = \frac{\pi \left(1 + \frac{1}{\sin \pi/10}\right)^2}{\pi + 4(10-1)} = \frac{\pi \left(1 + \frac{1}{\sin 18^\circ}\right)^2}{\pi + 36} = 1.44. \quad (13, b)$$

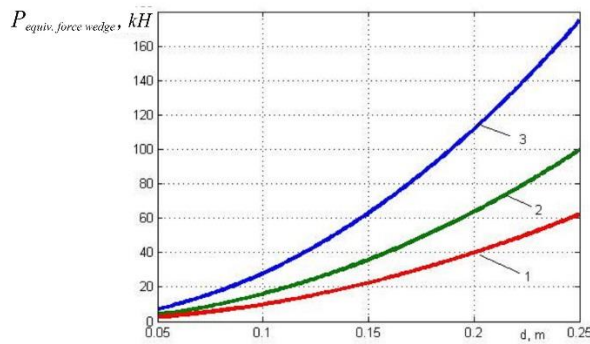


Figure 2. Dependence of the frontal resistance of the wedge drive on the diameter of the communication, offered: 1 – rigid plastic clay; 2 – semi-solid loam; 3 – solid loam.

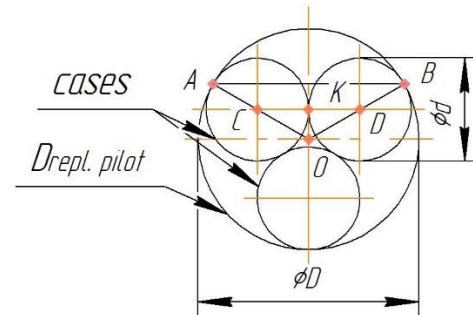


Figure 3. Determination of opening diameter is at a group gasket n- casing.

A lateral soil pressure is applied around the perimeter of the tip, which creates additional resistance from the forces of soil friction along the side walls and rounded edges of the tip.

The average soil pressure on the side walls and edges of the tip is equal:

$$q_{\text{mid}} = 2c \cdot \operatorname{tg} \left(\frac{\pi}{4} + \frac{\varphi_0}{2} \right) + \frac{a_q}{2} h. \quad (14)$$

where c – soil adhesion coefficient; φ_0 – angle of internal friction of the soil; a_q – proportionality factor ($a_q = 0.026$ MPa/m); h – depth of replaceable pilot placement (depth of laying of communications).

The length of the perimeter of the tip housing is equal:

$$L_{\text{perimeter}} = 2(n-1)d + \pi d. \quad (15)$$

The resistance from friction forces is determined by the area of the lateral surface of the tip and the average pressure is equal to:

$$F_{\text{friction}} = [\pi d + 2(n-1)d] h_{\text{wedge}} f \left[2c \cdot \operatorname{tg} \left(\frac{\pi}{4} + \frac{\varphi_0}{2} \right) + \frac{a_q}{2} h \right], \quad (16)$$

where h_{wedge} – width of lateral surface replaceable pilot; f – coefficient of soil friction on the tip material.

Then the total drive resistance will have an overview:

$$P_{\Sigma} = \frac{\pi + 2(n-1)}{8} d^2 E_{\text{soil}} (1 + f \operatorname{ctg} \beta) + [\pi d + 2(n-1)d] h_{\text{wedge}} f \left[2c \cdot \operatorname{tg} \left(\frac{\pi}{4} + \frac{\varphi_0}{2} \right) + \frac{a_q}{2} h \right]. \quad (17)$$

Dependence P_{Σ} as a function of d for $n = 2$ shown in the figure 4 formulas (12, 15, 16, 17).

Dependence was obtained to determine the total soil resistance at its puncture by the proposed soil perforation working equipment taking into account the friction forces on its lateral surface.

The prospect of further research is to theoretically determine the equivalent dimensions of a wedge tip with rounded edges, to obtain rectangular openings, to remove the effect of friction on the cavity wall, and to determine the optimal diameter of the cases, which are laid on the soil type and its humidity.

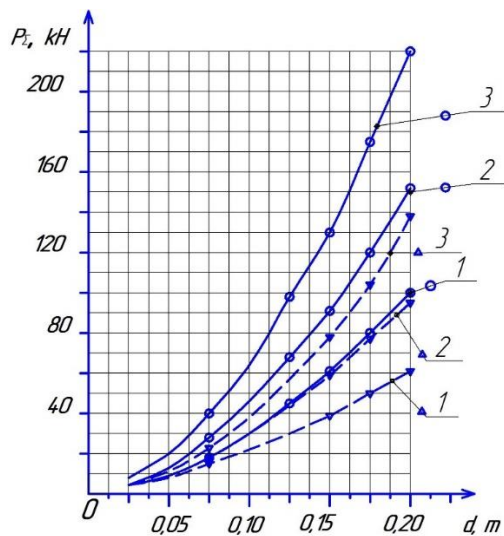


Figure 4. Dependence of the total resistance of the wedge tip on the diameter of the communications that are laid: 1 – rigid-plastic clay; 2 – semi-solid loam; 3 – solid loam; the point shows the results for the conical tip, and the triangle shows the results for the tip in the form of a wedge.

According to the graph in the figure 4 the total perforation resistance of the soil tip depends on the diameter of the tubes that are inserted into the caliber portion, the width of the rectangle of which lies within the optimum diameter of the conical puncture. Significant effort up to 2 times also differs from the type of soil.

5. Conclusions

It is established that with a static puncture of the soil with a conical tip, its diameter is limited by the calculated optimal value, which is not sufficient for the simultaneous laying of two or more linear-long underground communications.

The proposed design of the working equipment for static perforation of the soil and trenchless pro-laying simultaneously two or more underground linear-extended objects in the form of a tip consisting of a perforation e wedge-shaped part with semicons and a calibrating part in the form of a half-cylinder rectangle.

It is established that the ratio of the force of the frontal resistance of the soil to perforation conical tips can be more than 1.76 times compared to the wedge tip, depending on the number of cases simultaneously laid.

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